REMARKS

In response to the objection in the Office Action dated 27 February 2004 (the "Office Action") concerning the drawings, replacement drawings are submitted in which empty diagram boxes are appropriately labeled. Acceptance of the replacement sheets and withdrawal of the objections is respectfully submitted. Two typographical errors in the Specification have also been corrected.

Claims 1, 3-23 and 26-40 were pending in this application prior to this amendment. Claims 1, 3-23 and 26-40 were rejected in the Office Action.

In response to the rejections under 35 USC 112 of claims 1, 9, 15, and 34, Applicants have amended claims 1, 9, 12, 15, 16, 19, 34, 39-40.

In the Office Action, the Examiner rejected claims 16-20, 23, and 26 under 35 U.S.C. 103(a) as being unpatentable over U.S. Patent No. 5,734,098 ("Kraus et al.") in view of "On-site, Near-Real-Time Monitoring of Scale Deposition" by Emmons et al. ("Emmons et al.") and US 4,092,858 ("Edgerton").

The examiner states that it would be obvious to combine the teaching of Kraus et al. in view of Emmons et al. with the principles of ultrasonic cleaning as Edgerton teaches. However, the piezoelectric structure of the sensor/cleaning device of Edgerton is a tube (FIG.1). Furthermore, the sensor is a temperature gradient sensor predominantly relying on the temperature flow between the two metallic coatings (see column 4, 50-56). In other words, the sensor of Edgerton is structurally and functionally different from the sensors of Kraus et al. and Emmons et al. The examiner fails to provide an obvious way of how Edgerton could be modified so as to provide a cleaning effect for the sensors of Kraus et al and Emmons et al., both of which are made of extremely thin disks of quartz. It is by no means obvious that such a thin disk sensor can be driven in a resonant mode of sufficient amplitude to create cavitation and thus remove deposits.

In connection with the operating mode, the examiner has not given weight to the element of operative frequency "in a resonance mode in a frequency range of 10 kHz to 250 kHz" (claim 1). Kraus et al. and Emmons et al are silent on the range. US Patent No. 5,201,215 ("Grenstaff et al.") discloses operating frequencies around 5MHz (FIG. 4, FIG. 5), i.e. more than 10 times higher.

Furthermore, the element of a "control loop between monitor and deposit removal" is neither disclosed nor suggested by Kraus et al. in view of Emmons et al. and Edgerton.

With regards to the obviousness rejection of claim 18, it is submitted that merely asserts that it would be obvious to provide the monitoring surface near sensitive equipment. However, Kraus et al. relates to method to observe a chemical process and the control of the process, not the protection of equipment, is its main focus. Emmons et al. refers to in a unspecific manner to on-line installation in surface equipment (column 1, paragraph 4 of page 392). Both cited references fail to teach the use of the monitor in proximity to sensitive equipment such as switches, valves etc.

With regards to the obviousness rejection of claim 19, it is submitted that Kraus et al. does not teach or suggest a monitoring surface similar to the monitoring surface of the invention. At this monitoring surface an analysis of the deposits takes place. Such an analysis of deposits is not found in Kraus et al.

With regards to the obviousness rejection of claim 20, the objection is essentially based on the assertion that Kraus et al. or Kraus et al. in view of Grenstaff et al. discloses a monitoring device operating in longitudinal mode. It is submitted that this assertion is not correct. As evidenced by the Chapter 48 (3 page extract) of The Electrical Engineering Handbook 2nd Edition 2000, CRC (attached as Exhibit A), it is established knowledge in the art to distinguish between longitudinal and shear modes. Both modes are regarded as orthogonal to each other and the wave propagation characteristics are different. The crystals used by Kraus et al., Grenstaff et al. and Emmons et al. are all without exception operated in shear mode. None of the cited document discloses or suggests the use of longitudinal oscillation mode.

With regards to the obviousness rejection of claim 23, it is stated that Kraus et al. discloses the use of a deposition inhibiting or removing chemical agent as part of a deposit removal system. In fact, Kraus et al. discloses a system "where a change in the characteristics of a fluid may indicate a processing problem which can be corrected through the addition of a chemical treatment" (column 5, 33-36). The processing problem referred to is a chemical process monitored through the sensor. The aim of Kraus et al. is to control this chemical process – not to attempt a removal of deposits. Therefore it is clearly erroneous to assume that Kraus et al. discloses a deposition removal system or the use of chemicals for such a purpose.

With regards to the obviousness rejection of claim 26 (amended), the deposition monitor "comprises an additional sensing system to analyze material deposited on the monitoring surface". No such sensor that specifically targets the monitoring surface is disclosed or suggested by Kraus et al.

With regards to the obviousness rejection of claim 34, it is submitted that none of the cited prior art reveals monitoring of thickness. However, in the application of monitoring scale it is the thickness, and not necessarily the amount of the deposits, which is the parameter of interest. Whether or not it is obvious to derive a relationship between the amount deposited and the thickness, it remains fact that both, Kraus et al and Emmons et al. fail to disclose such a relationship.

With regards to the obviousness rejection of claim 35, the objection is essentially based on the assertion that Kraus et al. or Kraus et al. in view of Grenstaff et al. discloses a monitoring device operating in longitudinal mode. It is submitted that this assertion is not correct. As evidenced by the Chapter 48 (3 page extract) of The Electrical Engineering Handbook 2nd Edition 2000, CRC, it is established knowledge in the art to distinguish between longitudinal and shear modes. Both modes are regarded as orthogonal to each other and the wave propagation characteristics are different. The crystals used by Kraus et al., Grenstaff et al. and Emmons et al. are all without exception operated in shear mode. None of the cited document discloses or suggests the use of longitudinal oscillation mode.

With regards to the obviousness rejection of claim 38, it is submitted that merely asserts that it would be obvious to provide the monitoring surface near sensitive equipment. However, Kraus et al. relates to method to observe a chemical process and the control of the process, not the protection of equipment, is its main focus. Emmons et al. refers to in a unspecific manner to on-line installation in surface equipment (column 1, paragraph 4 of page 392). Both cited references fail to teach the use of the monitor in proximity to sensitive equipment such as switches, valves etc.

With regards to claim 39, the examiner states that it would be obvious to combine the teaching of Kraus et al. in view of Emmons et al. with the principles of ultrasonic cleaning as Edgerton teaches. However, the piezoelectric structure of the sensor/cleaning device of Edgerton is a tube (FIG.1). Furthermore, the sensor is a temperature gradient sensor predominantly relying on the temperature flow between the two metallic coatings (see column 4, 50-56). In other words, the sensor of Edgerton is structurally and functionally

different from the sensors of Kraus et al. and Emmons et al. The examiner fails to provide an obvious way of how Edgerton could be modified so as to provide a cleaning effect for the sensors of Kraus et al and Emmons et al., both of which are made of extremely thin disks of quartz. It is by no means obvious that such a thin disk sensor can be driven in a resonant mode of sufficient amplitude to create cavitation and thus remove deposits.

The element of a "control loop between monitor and deposit removal" is neither disclosed nor suggested by Kraus et al. in view of Emmons et al. and Edgerton.

With regards to claim 40, the examiner states that it would be obvious to combine the teaching of Kraus et al. in view of Emmons et al. with the principles of ultrasonic cleaning as Edgerton teaches. However, the piezoelectric structure of the sensor/cleaning device of Edgerton is a tube (FIG.1). Furthermore, the sensor is a temperature gradient sensor predominantly relying on the temperature flow between the two metallic coatings (see column 4, 50-56). In other words, the sensor of Edgerton is structurally and functionally different from the sensors of Kraus et al. and Emmons et al. The examiner fails to provide an obvious way of how Edgerton could be modified so as to provide a cleaning effect for the sensors of Kraus et al and Emmons et al., both of which are made of extremely thin disks of quartz. It is by no means obvious that such a thin disk sensor can be driven in a resonant mode of sufficient amplitude to create cavitation and thus remove deposits.

In summary, Applicant's believe that the examiner's observations are erroneous on a number of points, including the question of transversal versus longitudinal mode, which are clearly two distinct modes of operating a quartz crystal. The frequency range of 10 Khz to 250 KHz is not disclosed in Kraus et al.. Further, there is no indication that Kraus et al contemplates the removal of deposits. Thirdly, the sensor of Edgerton is a different class of device. And the examiner fails to show that the devices of Kraus et al. or Emmons et al. are capable of being operated in the "cavitation" mode as used by Edgerton to remove deposits. Therefore, Applicants believe that being restricted to those claims which were deemed allowable in the Office Action is not supported by the prior art cited.

With regards to the independent claim 1, none of the cited documents shows or suggests a deposit monitoring system operated in longitudinal mode. With regards to independent claim 16, none of the cited documents shows or suggests a monitor for fluid characteristics with a monitoring surface cleaned by an acoustic device. With regards to independent claim

34, none of the cited documents shows or suggests a deposit monitor for the accurate measurement of the thickness of layers.

In light of the above amendments and remarks, applicants believe that the present application and claims 1, 3-23 and 26-40 are in proper condition for allowance. Such allowance is earnestly requested. If the Examiner is contemplating any action other than allowance of all pending claims, the Examiner is urged to contact Applicants' undersigned representative, Mr. William Batzer.

In the event that a fee or refund is due in connection with this Amendment, the Commissioner is hereby authorized to charge any underpayment or credit any overpayment to Deposit Account No. 19-0615.

Respectfully submitted,

By: ______________

William B. Batzer
Registration N° 37,088

Date: May 27, 2004
Schlumberger-Doll Research
36 Old Quarry Road
Ridgefield, Connecticut 06877-4108
Phone: (203) 431-5506

48

Ultrasound

48.1 Introduction
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Gerald W. Farnell
McGill University

48.1 Introduction

In electrical engineering, the term *ultrasonics* usually refers to the study and use of waves of mechanical vibrations propagating in solids or liquids with frequencies in the megahertz or low gigahertz ranges. Such waves in these frequency ranges have wavelengths on the order of micrometers and thus can be electrically generated, directed, and detected with transducers of reasonable size. These ultrasonic devices are used for signal processing directly in such applications as filtering and pulse compression and indirectly in acousto-optic processors; for flaw detection in optically opaque materials; for resonant circuits in frequency control applications; and for medical imaging of human organs, tissue, and blood flow.

48.2 Propagation in Solids

If the solid under consideration is elastic (linear), homogeneous, and nonpiezoelectric, the components, u_i, of the displacement of an infinitesimal region of the material measured along a set of Cartesian axes, x_i, are interrelated by an equation of motion:

$$\rho \frac{\partial^2 u_i}{\partial t^2} = \sum_j \sum_k \sum_l c_{ijkl} \frac{\partial^2 u_j}{\partial x_k \partial x_l}, \qquad \text{Form: } \rho \frac{\partial^2 u}{\partial t^2} = c \frac{\partial^2 u}{\partial x^2} \tag{48.1}$$

where ρ is the mass density of the material and c_{ijkl} $(i, j, k, l = 1, 2, 3)$ is called the stiffness tensor. It is the set of proportionality constants between the components of the stress tensor T and the strain tensor S in a three-dimensional Hooke's law (form: $T = cS$ with $S = \partial u/\partial x$). In Eq. (48.1) and in the subsequent equations the form of the equation is shown without the clutter of the many subscripts. The form is useful for discussion purposes; moreover, it gives the complete equation for cases in which the propagation can be treated as one dimensional, i.e., with variations in only one direction, one component of displacement, and one relevant c.

In an infinite medium, the simplest solutions of Eq. (48.1) are plane waves given by the real part of

$$u_i = U_i e^{-jk\left(\sum_j L_j x_j - Vt\right)} \qquad \text{Form: } u = Ue^{j(\omega t - kx)} \tag{48.2}$$

where the polarization vector has components U_i along the axes. The **phase velocity** of the wave V is measured along the propagation vector **k** whose direction cosines with respect to these axes are given by L_i. Substituting

the assumed solutions of Eq. (48.2) into Eq. (48.1) gives the third-order eigenvalue equations, usually known as the Christoffel equations:

$$\sum_j \sum_k \sum_l L_k L_l c_{ijkl} U_j = \rho V^2 U_i, \qquad \text{Form: } (c - \rho V^2)U = 0 \tag{48.3}$$

The three eigenvalues in Eq. (48.3) give three values of ρV^2 and hence the phase velocities of three waves propagating in the direction of positive k and three propagating in the negative k direction. The eigenvectors of the three forward solutions give the polarization vector for each, and they form a mutually perpendicular triad. The polarization vector of one of the plane waves will be parallel, or almost parallel, to the k vector, and it is called the longitudinal wave, or quasi-longitudinal if the displacement is not exactly parallel to k. The other two waves will have mutually perpendicular polarization vectors, which will each be perpendicular, or almost perpendicular, to the k vector. If the polarization is perpendicular, the wave is called a transverse or shear wave; if almost perpendicular, it is called quasi-shear. The three waves propagate independently through the solid, and their respective amplitudes depend on the exciting source.

In an isotropic medium where there are only two independent values of c_{ijkl} in Eq. (48.1), there are one longitudinal wave and two degenerate shear waves. The phase velocities of these waves are independent of the direction of propagation and are given by

$$V_l = \sqrt{\frac{c_{1111}}{\rho}} \quad \text{and} \quad V_s = \sqrt{\frac{c_{1212}}{\rho}} \tag{48.4}$$

The phase velocities in isotropic solids are often expressed in terms of the so-called Lame constants defined by $\mu = c_{1212}$ and $\lambda = c_{1111} - 2c_{1212}$. The longitudinal velocity is larger than the shear velocity. Exact velocity values depend on fabrication procedures and purity, but Table 48.1 gives typical values for some materials important in ultrasonics.

In signal processing applications of ultrasonics, the propagating medium is often a single crystal, and thus a larger number of independent stiffness constants is required to describe the mechanical properties of the medium, e.g., three in a cubic crystal, five in a hexagonal, and six in a trigonal. Note that while the number of independent constants is relatively small, a large number of the c_{ijkl} are nonzero but are related to each other by the symmetry characteristics of the crystal. The phase velocities of each of the three independent plane waves in an anisotropic medium depend on the direction of propagation. Rather than plotting V as a function of angle of propagation, it is more common to use a **slowness surface** giving the reciprocal of V (or $\mathbf{k} = \omega / V$ for a given ω) as a function of the direction of k. Usually planar cuts of such slowness surfaces are plotted as shown in Figs. 48.1(a) and (b).

In anisotropic materials the direction of energy flow (the ultrasonic equivalent of the electromagnetic Poynting vector) in a plane wave is not parallel to **k.** Thus the direction of **k** is set by the transducer but the energy flow or beam direction is normal to the tangent to the slowness surface at the point corresponding to **k.** The direction of propagation (of **k**) in Fig. 48.1 lies in the basal plane of a cubic crystal, here silicon. At each angle there are three waves—one is pure shear polarized perpendicular to this plane, one is quasilongitudinal for most angles, while the third is quasi-shear. For the latter two, the tangent to the slowness curves at an arbitrary angle is not normal to the radius vector, and thus there is an appreciable angle between the direction of energy flow and the direction of **k**. This angle is shown on the diagram by the typical **k** and **P** vectors, the latter being the direction of energy flow in an acoustic beam with this **k.** Along the cubic axes in a cubic crystal, the two shear waves are degenerate, and for all three waves the energy flow is parallel to **k.** When the particle displacement of a mode is either parallel to the propagation vector or perpendicular to it and the energy flow is parallel to **k,** the mode is called a **pure mode.** The propagation vector in Fig. 48.1(b) lies in the basal plane of a trigonal crystal, quartz.

When ultrasonic waves propagate in a solid, there are various losses that attenuate the wave. Usually the attenuation per wavelength is small enough that one can neglect the losses in the initial calculation of the

Defining Terms

Characteristic impedance: Ratio of the negative of the stress to the particle velocity in an ultrasonic plane wave.

Form: Term used to indicate the structure and dimensions of a multiterm equation without details within component terms.

Phase velocity: Velocity of propagation of planes of constant phase.

Piezoelectric transducers: Devices that convert electric signals to ultrasonic waves, and vice versa, by means of the piezoelectric effect in solids.

Pure longitudinal and shear waves (modes): Ultrasonic plane waves in which the particle motion is parallel or perpendicular, respectively, to the wave vector and for which energy flow is parallel to the wave vector.

Slowness surface: A plot of the reciprocal of the phase velocity as a function of direction in an anisotropic crystal.

Related Topics

15.2 Speech Enhancement and Noise Reduction • 49.2 Mechanical Characteristics

References

B.A. Auld, *Acoustic Fields and Waves in Solids,* 2nd ed., Melbourne, Fla.: Robert E. Krieger, 1990.

E.A. Gerber and A. Ballato, *Precision Frequency Control,* vol.1, *Acoustic Resonators and Filters,* Orlando, Fla.: Academic Press, 1985.

G.S. Kino, *Acoustic Waves: Devices Imaging and Analog Signal Processing,* Englewood Cliffs, N.J.: Prentice-Hall, 1987.

Landolt-Bornstein, *Numerical Data and Functional Relationships in Science and Technology: Gp III Crystal and Solid State Physics,* vol. 11, *Elastic, Piezoelectric, Pyroelectric and Piezooptic Constants of Crystals,* Berlin: Springer-Verlag, 1979.

W.P. Mason and R.N. Thurston (Eds.), *Physical Acoustics, Principles and Methods,* multivolume series, New York: Academic Press.

H.B. Meire, *Basic Ultrasound,* New York: Wiley, 1995.

J.F. Rosenbaum, *Bulk Acoustic Wave Theory and Devices,* Boston: Artech House, 1988.

Further Information

The main conferences in the ultrasonics area are the annual Ultrasonics Symposium sponsored by the IEEE Ultrasonics, Ferroelectrics and Frequency Control Society and the biannual Ultrasonics International Conference organized by the journal *Ultrasonics,* both of which publish proceedings. The periodicals include the *Transactions of the IEEE Ultrasonics, Ferroelectrics and Frequency Control Society,* the journal *Ultrasonics* published by Butterworth & Co., and the *Journal of the Acoustical Society of America.* The books by Kino and by Rosenbaum in the References provide general overviews of the field.